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PRESSURE MEASUREMENTS IN A RAPIDLY ROTATING AND CONING, HIGHLY VISCOUS FLUID

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Rotating Liquids

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (bja)

The pressure on the endwall of a rapidly rotating and coning liquid-filled cylinder was measured. A gyroscope was used to generate the spin and coning motion. The Reynolds number based upon the radius, gyroscope spin, and liquid kinematic viscosity was 8.8.

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I. INTRODUCTION

Most of the research conducted on the stability and motion of spinning liquid-filled containers is for cases where the rotational force is much larger than the viscous force, i.e., high Reynolds number flows. The Reynolds number is defined as $Re = a^2\dot{\phi}/\nu$, where a is the radius of the cylinder, $\dot{\phi}$ is the spin, and ν is the liquid kinematic viscosity. Yawsonde-instrumented projectiles have exhibited large yaw and rapid despin for small Reynolds (Re) numbers: $10 < Re < 50$.[1,2,3,4] D'Amico has used a gyroscope to determine the liquid-induced yaw moment for $5 < Re < 12{,}000$.[5] Also, Miller has used a spin fixture to determine the liquid-induced roll moment for low Reynolds number.[6] This study supplements previous low Reynolds number research efforts by reporting pressure measurements. Unlike previous efforts where integral effects such as yaw or despin moments were measured, the pressure measurements provide a basis for fundamental comparisons with analytical or numerical methods for low Reynolds number rotating flows.

II. DESCRIPTION OF EXPERIMENT

The coning device used by Whiting, shown in Figures 1a and 1b, was used in these experiments.[7] A detailed description of the pressure measurement

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1. *W. P. D'Amico and M. C. Miller, "Flight Instability Produced by a Rapidly Spinning, Highly Viscous Liquid," Journal of Spacecraft and Rockets, Vol. 16, No. 1, January-February 1979, pp. 62-64.*

2. *W. P. D'Amico, W. H. Clay, and A. Mark, "Diagnostic Tests for Wick-Type Payloads and Highly Viscous Liquids," US Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, BRL Memorandum Report ARBRL-MR-02913, April 1979 (AD A072812).*

3. *W. P. D'Amico and W. H. Clay, "High Viscosity Liquid Payload Yawsonde Data for Small Launch Yaws," US Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, BRL Memorandum Report ARBRL-MR-03029, June 1980 (AD A088411).*

4. *W. P. D'Amico and R. J. Yalamanchili, "Yawsonde Tests of the 8-Inch XM877 Binary Projectile: Phase I," US Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, BRL report in publication.*

5. *W. P. D'Amico, "Instabilities of a Gyroscope Produced by Rapidly Rotating Highly Viscous Liquids," US Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, BRL Memorandum Report ARBRL-MR-03285, June 1983 (AD A130974).*

6. *Miles C. Miller, "Flight Instabilities of Spinning Projectiles Having Non-Rigid Payloads," Journal of Guidance, Control, and Dynamics, Vol. 5, March-April 1982, pp. 151-157.*

7. *Richard D. Whiting, "An Experimental Study of Forced Asymmetric Oscillations in a Rotating Liquid-Filled Cylinder," US Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, BRL Technical Report ARBRL-TR-02376, October 1981 (AD A107948).*

system and the data reduction is located in Reference 7, but a review will be made here. The cylinder was filled to 100% with a silicon oil (kinematic viscosity (ν) of 60,000 cs and density (ρ) of 0.979 gm/cc), and all spinning parts were dynamically balanced. The rotor was inclined to the vertical at a known angle (ε) and held in place by a bushing that rested in a cam which was driven by a DC motor. The cylinder was spun by a DC motor (83.3 Hz), and the liquid was allowed to achieve a rigid body rotation. For a preselected precession frequency, sufficient time was allowed for a steady coning motion to occur. Hence, the cylinder is in constant angle, steady coning motion. The oscillatory, steady state pressures of the liquid were then measured. Two miniature pressure transducers were embedded into an insert that formed the bottom endwall of the cylinder which was located within the rotor. These transducers measured the absolute pressure of the liquid within the cylinder.

Figure 2 provides a schematic of the pressure measurement/telemetry system. The voltage outputs from the pressure transducers were amplified for telemetry. The gain of the amplifiers was typically 700 for frequencies between 50-100 Hz. The amplified outputs were in turn fed to voltage controlled oscillators (VCO's or subcarrier oscillators), mixed, and telemetered by a 250 MHz transmitter. The amplified pressure signals were recovered by using a receiver and two discriminators. It would then have been possible to digitize the data. However, since it was anticipated that the pressure response would be sinusoidal, a spectrum analyzer was used to determine frequency and amplitude components. A Hewlett-Packard 3582A spectrum analyzer was used. The output of the analyzer (which is volts rms) was read by a Hewlett-Packard 9845B computer via an IEEE-488 instrument bus and stored for further processing. The data were converted from volts rms to volts, rescaled by the amplifier gain, and translated into pressure by a previously determined calibration. Table 1 establishes terminology and conventions for pressure amplitudes.[8] Previous comparisons between computed pressures by Murphy[9] and Gerber et al[10] for high Reynolds numbers and this measurement system have been consistent.

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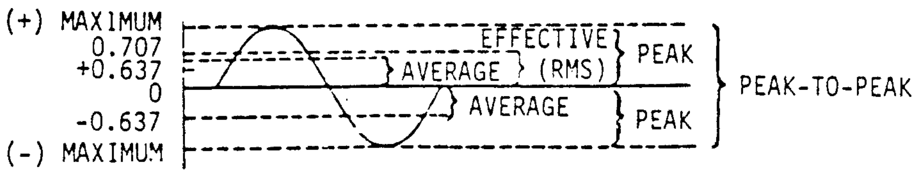
8. J. D. Lenk, Handbook of Practical Electronic Tests and Measurements, Prentice-Hall Inc., Englewood Cliffs, New Jersey, 1969.

9. Charles H. Murphy, "Angular Motion of a Spinning Projectile With a Viscous Liquid Payload," US Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, BRL Memorandum Report ARBRL-MR-03194, August 1982, AD A118676. (See also Journal of Guidance, Control, and Dynamics, Vol. 6, July-August 1983, pp. 280-286.)

10. N. Gerber, R. Sedney, and J. M. Bartos, "Pressure Moment on a Liquid-Filled Projectile: Solid Body Rotation," US Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, BRL Technical Report ARBRL-TR-02422, October 1982 (AD A120567).

TABLE 1. VOLTAGE MEASUREMENT RELATIONSHIPS (REF. 8)

Given ↓	Average	Effective (RMS)	Peak	Peak-to-Peak
Average	-----	1.11	1.57	3.14
Effective (RMS)	0.900	----	1.411	2.831
Peak	0.637	0.707	-----	2.00
Peak-to-Peak	0.3181	0.3541	0.500	-----



For the present set of experiments, pressures were measured from a single transducer (radial location of 21.2 mm). The coning angle was fixed at 2.00 degrees. The direction of the precession is controllable. A positive sense is considered to be in the direction of spin, which is typical for spin-stabilized projectiles, but data were taken for both positive and negative senses. The spin rate was held constant, while the coning frequency (and direction) were varied. The ratio of the coning frequency to the spin frequency is defined as τ and had the following range: $-0.15 < \tau < 0.15$. A single cylinder with a height and diameter of 19.99 cm and 6.35 cm, respectively, was used (aspect ratio (c/a) = 3.148).

III. EXPERIMENTAL RESULTS

The experimental conditions and results are listed in Tables 2 and 3. Results are plotted in Figure 3 for pressure coefficient versus τ. Pressures and pressure coefficients were obtained as follows:

$$P(\text{dynes/cm}^2) = \frac{\text{Amplitude(v rms)} \times (1.411 \text{ v/v rms}) \times \text{Pressure Calibration (dynes/cm}^2)}{\text{Amplifier Gain}}$$

and

$$C_p = \frac{P(\text{dynes/cm}^2)}{\epsilon \, \rho \, a^2 \, \dot{\phi}^2}$$

TABLE 2. TEST CONDITIONS

Spin	=	83.3 Hz
Coning angle	=	2.00 degrees
Fill ratio	=	100%
Cylinder height	=	19.99 cm
Cylinder diameter	=	6.35 cm
Nominal fluid viscosity	=	60,000 cs
Nominal fluid density	=	0.979 gm/cc
Pressure calibration	=	0.2232 psi/mv
	=	69.75 dynes/cm^2/mv
Amplifier gain	=	710.0

TABLE 3. EXPERIMENTAL RESULTS

Spin Period (ms)	Coning Period (ms)	τ	Amplitude (volts rms)	Pressure (dynes/cm^2)	C_p
12.0	84.00	.1429	.494	1.51×10^4	.160
12.0	90.00	.1333	.460	1.41×10^4	.149
12.0	100.00	.1200	.411	1.26×10^4	.133
12.0	120.00	.1000	.332	1.02×10^4	.107
12.0	150.00	.0800	.261	8.00×10^3	.084
12.0	175.00	.0686	.226	6.93×10^3	.073
12.0	-240.00	-.0500	.144	4.41×10^3	.047
12.0	-200.00	-.0600	.170	5.21×10^3	.055
12.0	-175.00	-.0686	.193	5.92×10^3	.062
12.0	-150.00	-.0800	.217	6.65×10^3	.070
12.0	-120.00	-.1000	.267	8.18×10^3	.086
12.0	-100.00	-.1200	.317	9.72×10^3	.103
12.0	-90.00	-.1333	.345	1.06×10^4	.112
12.0	-84.00	-.1429	.371	1.14×10^4	.120

The data in Figure 3 indicate that C_p varies linearly with τ. The data has been fit with the following results: prograde motion $C_p = 1.153\ \tau + .008$, retrograde motion $C_p = 0.7823\ \tau + .008$. This response curve is not typical for high Reynolds numbers rotating flows. Typically, rotating liquids support waves and an interaction between a wave frequency (an eigenfrequency) and the coning frequency produce a resonant type response where the pressure (and resulting destabilizing moments) become large over a very small range of τ. Response curves similar to Figure 3 were observed by D'Amico for $10 < Re < 100$ for yaw moments. Murphy[9] has suggested that both low and high Reynolds number response stem from the same phenomena. For low Reynolds numbers, however, large viscous dissipation flattens the response curve over the experimental range of coning frequencies and yields a seemingly linear behavior for small τ. Such a conjecture may be difficult to investigate analytically, since rapid coning frequencies are difficult to achieve. However, this thesis could be tested using three dimensional, incompressible Navier-Stokes codes that are currently under development.[11]

IV. SUMMARY

The pressure on the endwall of a rapidly rotating and coning cylinder was measured for a Reynolds number of 8.8. Prograde and retrograde coning motion yielded pressure coefficients that varied linearly with the dimensionless coning frequency. These are the only pressure data that are available for a direct comparison with analytical or numerical methods at low Reynolds number. Previously, only yaw or despin moments were measured.

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11. S. R. Chakravarthy, *"Upwind Schemes for the Navier-Stokes Equations Governing Fluid Motion in Spinning Shells," BRL Contractor report in publication.*

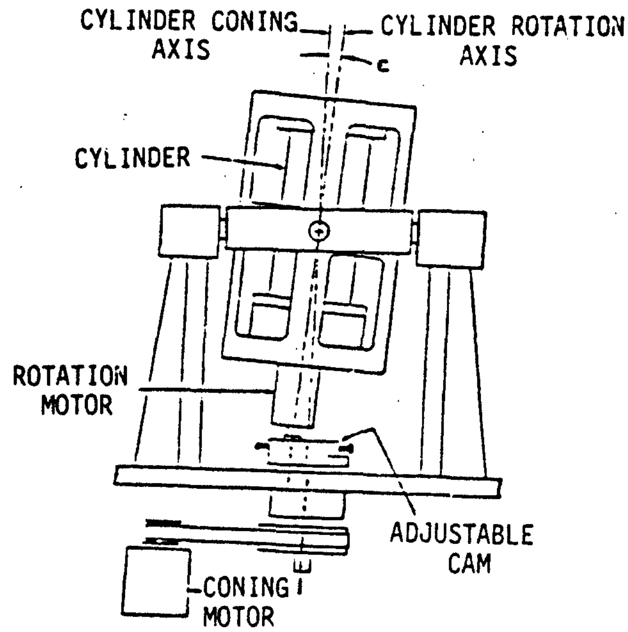

Figure 1a. Test Apparatus.

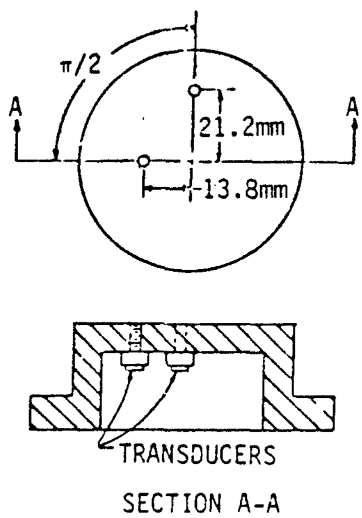

Figure 1b. Placement of Pressure Transducers.

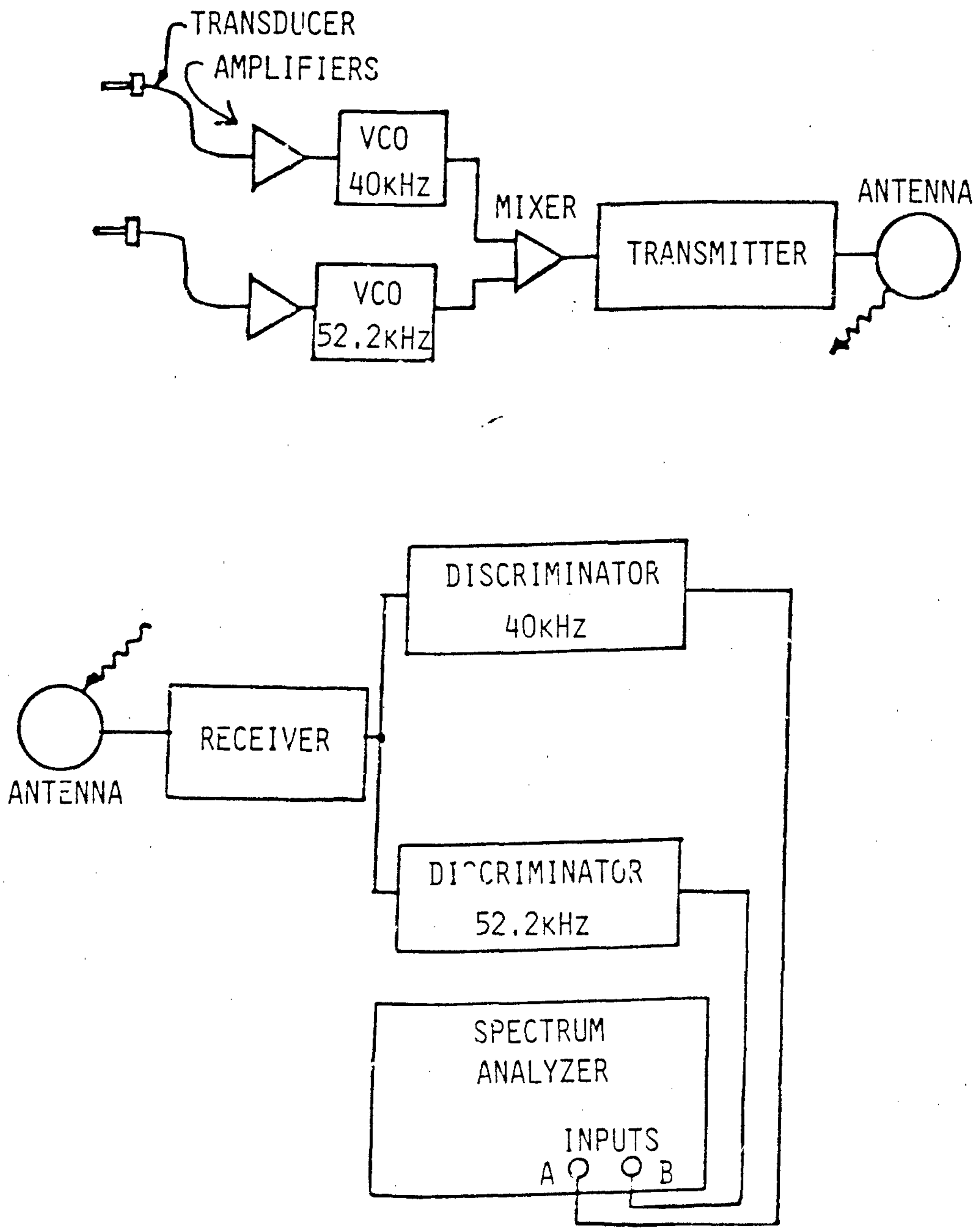

Figure 2. Schematic of Experimental Hardware for Pressure Measurement.

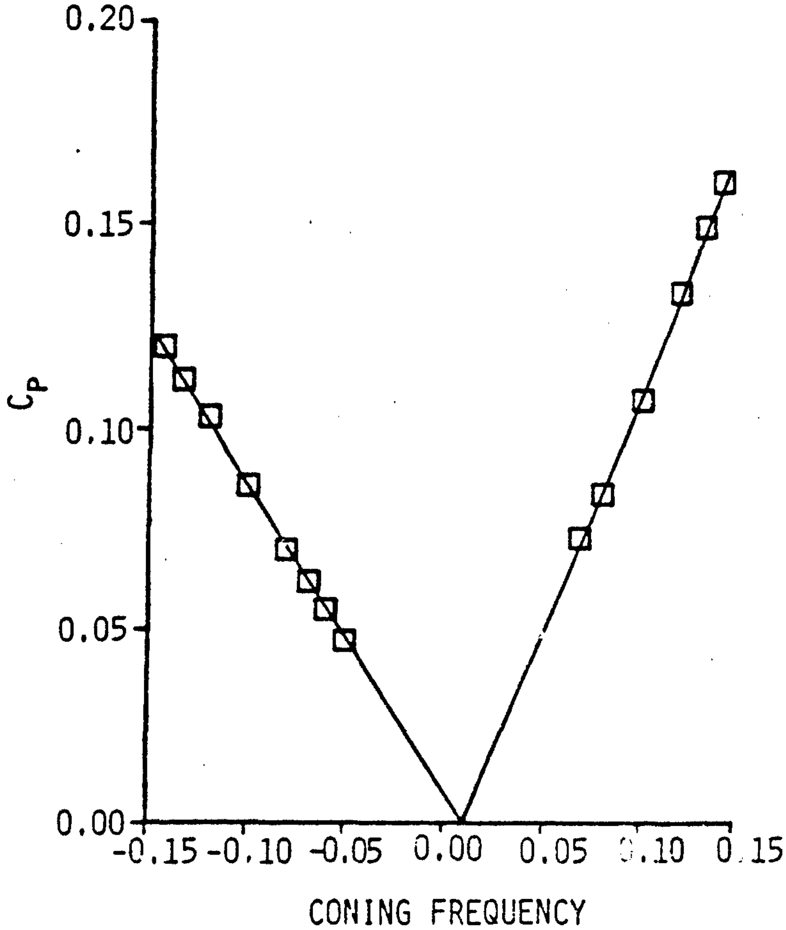

Figure 3. Pressure Coefficient Versus Coning Frequency for Re = 8.8.

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6. Miles C. Miller, "Flight Instabilities of Spinning Projectiles Having Non-Rigid Payloads," Journal of Guidance, Control, and Dynamics, Vol. 5, March-April 1982, pp. 151-157.

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